

**MODELLING THE EFFECT OF
NUTRIENT SUPPLY, TEMPERATURE
AND LIGHT INTENSITY ON
CNIDARIAN-ALGAE SYMBIOSIS**

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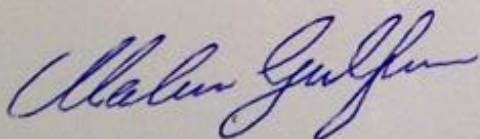
A THESIS SUBMITTED IN FULFILMENT OF THE REQUIERMENTS FOR THE
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i. CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

 07/08/2013

Malin Gustafsson

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ii. PUBLICATIONS

PEER REVIEWED JOURNAL ARTICLES ARISING DIRECTLY FROM THIS THESIS

Chapter 2:

Gustafsson, M. S. M., M. E. Baird, and P. J. Ralph. 2013. The interchangeability of autotrophic and heterotrophic nitrogen sources in Scleractinian coral symbiotic relationships: A numerical study. *Ecological Modelling* **250**: 183-194.

Chapter 3:

Gustafsson, M. S. M., M. E. Baird, and P. J. Ralph. (in press). Modeling photoinhibition and bleaching in Scleractinian coral as a function of light, temperature and heterotrophy. *Limnology and Oceanography*.

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Table 5.1: Ecology state variables

Table 5.2: Model equations associated with corals

Table 5.3: Model parameters.

vi. ABBREVIATIONS

| | |
|--------------------------------|--|
| APX | Ascorbate peroxidises |
| C | Carbon |
| CCM | Carbon Concentrating Mechanism |
| Chl | Chlorophyll |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DIC | Dissolved Inorganic Carbon |
| DIN | Dissolved Inorganic Nitrogen |
| DOM | Dissolved Organic Matter |
| ETC | Electron Transport Chain |
| e ⁻ | Electron |
| F _v /F _m | Maximum quantum yield of photosystem II |
| IPCC | Intergovernmental Panel of Climate Change |
| H ₂ O ₂ | Hydrogen peroxide |
| MTL | Mass Transfer Limited |
| N | Nitrogen |
| NOAA | National Oceanic and Atmospheric Administration |
| NPQ | Non-photochemical quenching |
| O ₂ ⁻ | Superoxide |

| | |
|------------------|--------------------------------|
| $^1\text{O}_2^*$ | Singlet oxygen |
| OEC | Oxygen Evolution Complex |
| POC | Particulate Organic Carbon |
| POM | Particulate Organic Matter |
| PON | Particulate Organic Nitrogen |
| ROS | Reactive Oxygen Species |
| PQ | Plastoquinone |
| PSII | Photosystem II |
| PSI | Photosystem I |
| SHOC | Spares Hydrodynamic Ocean Code |
| SOD | Superoxide dismutase |
| SST | Sea Surface Temperature |

vii. ABSTRACT

Understanding the symbiotic association between a coral host and their algae symbiont is essential if we are to be able to simulate and predict how expected changes in ocean sea surface temperatures and other environmental conditions associated with climate change may influence coral reefs in the future. In this thesis a mechanistic coral-algae symbiosis model is proposed, a model which captures the interaction between a heterotrophic host and an autotrophic symbiont with varying sources of nutrients, and various temperature and light intensities. This modelling effort includes mathematical representations of important physiological processes, such as growth, respiration, photosynthesis, calcification, translocation of photosynthates, mortality and mucus production, as well as photoinhibition, ROS production and bleaching. Validating the model using experimental data, showed the model capable of capturing the nutrient dynamics between the environment, the cnidarian host and the symbiotic algae, photoinhibition and bleaching as a function of elevated temperature and light, as well as the mitigating effects heterotrophic feeding may have during elevated thermal stress.

The basic coral symbiosis model, first developed, considered the nutrient dynamics of the symbiosis. The coral acquires nitrogen (N) through two processes, uptake of dissolved inorganic nitrogen (V_{DIN}^H) and heterotrophic feeding (Z_N). Numerical experiments were used to highlight the importance of these different sources of N for coral survival and growth. The model outputs showed the importance of the algae symbionts to the coral host as a source of both N and C when the feeding rate was limited. In contrast, with no light or low light, conditions under which the symbiont population dies, the host was able to survive if Z_N was sufficient to sustain its metabolic requirements. Translocation and recycling of nutrient were shown to be two of the most important features of this model, emphasizing why it is essential to resolve host and symbiont in a coral model.

During the second phase of this thesis a photoinhibition and bleaching model was added to the basic symbiosis model. The resulting modelled rate of bleaching depended on temperature, light intensity and the potential for heterotrophic feeding. The validation showed that the model was capable of capturing both the diurnal change in the state of the photosystem, as well as changes in the symbiont population and the coral host caused by different temperature, light and feeding treatments. Elevated temperatures and light led to a degradation of the photosystem and the expulsion of symbiont cells. If the coral fed heterotrophically, this degradation of the photosynthetic apparatus due to temperature and light stress was reduced, but still a clear decrease in F_v/F_m and cell numbers was observed when the coral was exposed to elevated temperature.

During the first two phases of this modelling effort it was noted that translocation and the uptake of inorganic nutrients needed more consideration. These processes were redefined using experimental (nanoSIMS) data of uptake and translocation in the symbiotic sea anemone *Aiptasia pulchella*. The new definitions proposed that the uptake of DIN and DIC from the environment were symbiont driven and directly associated with photosynthetic activity. The new translocation definition has two components including a representation of the “host release factor” as well as a release of excess photosynthates. This exercise also allowed us to show that the model worked well for a symbiotic association other than the corals.

The final part of this project was to incorporate the coral symbiosis model into a reef scale fully coupled hydrodynamic biogeochemical model of Heron Island Reef. Due to the high complexity of the model a simplified version of the basic symbiosis model was included. Even so the month long model runs showed how the coral influenced the nutrient dynamics over the reef and how changes in water column properties, water velocity and bottom friction influenced coral uptake of nutrients.

The model developed in this thesis highlights that the interchangeability of N sources, and the ability to exchange and recycle nutrients in the host-symbiont system, is the key to coral survival in nutrient poor environments. The photoinhibition model showed that heterotrophic feeding can mitigate the effect of

temperature and light stress as it enhances repair rates and tissue synthesis. The model is also applicable to other host-symbiont associations (such as the sea anemone) and it can be decoupled and used for the animal or the algae part separately. This model is a good tool to explore host-symbiont interactions, however there is always room for improvement and further development.